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Major issues and solutions in the heat-metering reform in China

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ABSTRACT

Charging heating fees based on floor space in China leaves building developers no economic returns on the investment to weatherize the buildings and install regulation devices with terminal equipment. Therefore, they lack incentives to improve the thermal insulation properties of the buildings. Tenants also lack incentives to efficiently use heat, opening windows to cool down rooms when they are overheated, without concern for the amount of heat wasted. In response, over the past decade, the Chinese government has invested large amounts of resources in an effort to promote energy conservation with heating systems by trying to change the fee method based on floor space to amount of heat used, but with little effect. The major issues related to reform with the heat-metering system are elaborated in this paper by comparing the pros and cons of several metering methods. Firstly, room temperatures are unable to be effectively adjusted using the current methods, meaning that the original intention to save energy cannot be achieved. Secondly, current heat-metering methods are not acceptable to users, which creates its own problems. Heat metering based on households in apartment buildings, the primary living space for Chinese people, causes two problems: the energy consumed by households located at the top or at the corner of buildings is two to three times higher than households located elsewhere within the building; heating fees may increase by 20–30% if surrounding households are not heated. Current metering methods are unable to effectively resolve these two problems, therefore, they are not accepted.

To overcome these difficulties, a proper metering and charging method must be developed which is both acceptable to users and able to guarantee good room temperature control at the same time. To achieve this goal, this paper presents a new method: the total heating fee of a building is allocated according to the accumulated on-time as well as the floor space of each household. Not only can this new method control the user behavior of opening windows or setting the starting point too high, but also resolve problems caused by location and heat transfer between households. It is also effective in promoting energy saving by users and appears to be acceptable to users. Survey results show that it is acceptable to a large number of users. It seems that this is the most practical way to reform the current methods for heat metering based on household use.

Contents

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1. Introduction: Why does China need to undergo reform in current practices of metering heat based on household?

According to statistics, there are 7.5 billion square meters that are heated in winter in Northern China's urban and county areas, with energy consumption equivalent to 0.143 billion tons of standard coal per year, accounting for 40% of the total operational cost of buildings in urban and county areas. As urbanization accelerates, the heating network in urban and county areas will also expand. It is expected that heating costs will increase to 0.3 billion tons of standard coal per year by 2020 at the current rate of development without energy conservation measures put in place [1]. Meanwhile, real data shows that heating costs in Northern China's urban and county areas are usually 20–30% higher than actual heating needed by the buildings. Thus, energy conservation for heating systems in Northern China's urban and county areas is of great significance.

Further study shows that there are two reasons for high energy consumption with heating systems: the first one is poor thermal insulation of building surfaces. The heat transfer coefficient of a building's external walls in Northern China is about 1 W/(m^2 K), with that of external windows about 4 W/(m^2 K), 1–2 times worse than that in Northern Europe (0.4 and 2 W/(m^2 K), respectively). This will lead to 1–2 times heat storage capacity. Reducing heating costs entails better thermal insulation, which means lowering the amount of heat consumed by the buildings themselves.

The second reason is poor temperature control. Some rooms are too cold and others too hot, so people who feel too hot tend to open windows to cool down. The problems with control systems can be divided into three categories: firstly, there are no control devices at all and users are unable to control the amount of heat used; secondly, although there are control devices, users do not know how to control or do control heat well because the devices are either not convenient to use or because of the poor performance of the devices; thirdly, people do not have the incentive to control heat usage because heating fees are charged based on floor space. So, the lack of access, knowledge and incentive for control methods causes 20–30% of energy used to be wasted [1].

Therefore, the key to reduce the heating cost in buildings in China is to improve the thermal properties of building surfaces to reduce the amount of heating needed and improve users control in central heating systems so that overheating and behaviors of opening windows can be avoided. The root cause of why such problems are unable to be solved is the heating fee is charged based on floor space. Heating fee per square meter is identical no matter what the thermal properties of the building is like, and heating is more or less supplied based on a maintained room temperature above 16 °C. This method does not incentivize a developer to improve the thermal properties and control devices of a building because they do not receive any benefit from their investment. On the other hand, based on this fee method, residents do not care about heat loss when they open windows if rooms are overheated. Therefore, charging method must be reformed from being based on floor space to being based on actual amount of heat used to eradicate such problems and to realize the following goals:

1) to incentivize developers to improve thermal properties;
2) to contain users' behavior to open windows (which refers to opening windows to cool down overheated rooms, the purpose of improving IAQ is not included);
3) make sure the room temperature set point is not too high; heating could also be terminated or the set point lowered when there are no users at home for a long period of time;
4) the heat-metering method is acceptable to the users so that it can be fully implemented.

Some experts at the World Bank pointed out in the mid-1990s, the key to promoting energy conservation with the central heating system in Northern China is to reform the fee and charges system. Chinese government offices also began considering this issue seriously, and adopted a series of policies, rules and bills to promote reform. The Ministry of Construction issued the "'Ninth Five Year Plan' (1996–2000) and a 2010 Plan of Building Energy Saving" in 1996 [2], which clearly pointed out that "heat meters and regulation devices installed in districts heating residential buildings are charged in accordance with the heat meters. Tests should be conducted in 1998 through pilot programs, and then the program can be launched; in 2000, it should be widely promoted in major cities; and basically be completed in 2010." The Ministry of Construction also issued Document 76 in 2000 on "Energy Conservation Regulations of Residential Buildings" [3], which demanded that starting "from October 2000, all new residences with central heating implement temperature regulation and install heat-metering devices, to charge based on the amount of heat used". The path of household heat metering is determined, and heating reform is determined to implement. In July 2003, the Ministry of Construction and other seven ministries jointly issued a document on "Guidance on a Pilot Project for Urban Heating System Reform" [4]. On December 8, 2005, they jointly issued a document on "Guidance for Further Promotion of Urban Heating System Reform" [5] again, which determined that "heating system reform be completed within roughly 2 years in all localities". On December 22, 2005, the Ministry of Construction asked local governments to develop detailed plans for reforming the fee method for heat systems. In the meantime, since 1993, many heat-metering pilot projects have been undertaken in Beijing, Tianjin, Changchun, Tangshan and Yantai and other cities.

However, progress in reforming the heat-metering system is lagging far behind expectations and it is very difficult to further develop despite the large amount of resources invested by the government to carry out pilot projects for reform. We should reconsider this situation and think through what the real problems are. Why is heat metering is not utilized as conveniently as electricity metering? Does the experience of more developed countries help resolve these problems? This paper tries to answer these questions and will hopefully be of use to scholars who are doing research on building energy conservation and policies related to heat meters and fee systems in China.

2. Problems with the application of several common heat-metering methods

Besides basing heating fees on floor space, there are two kinds of fee methods that are being tested [6–10]. One is to be charged on a household basis directly; a heat meter is installed on the radiator inlet which will directly record while a thermostatic valve is installed on the radiator and regulated. The other method is to install a calorimeter on the main supply pipe to the building and keep a record of the total heating consumption of the whole building, the heat is then distributed to each household in a certain way. There are three ways to distribute heat: according to heat-allocation meters installed on the radiators, according to floor space, or according to hot water meters in each household.

Other methods are also being tested in China. Heat usage may also be measured according to household calorimeters or temperature plus floor space, etc., as shown in Fig. 1. Such charging methods are based on calorimeter records at the entrance of the building, with the total cost shared by all the households inside the building. Therefore, the total heating cost of buildings with better thermal insulation properties is lower and the cost on each household is lower and vice versa. Such methods can encourage improvement of thermal properties in structures and energy-efficient buildings.

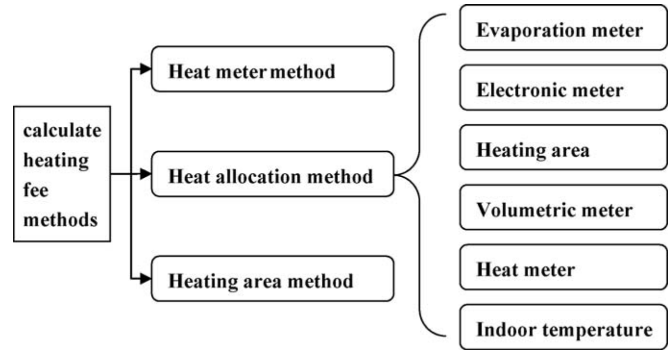


Fig. 1. Heat-metering methods already in place or being used in trials in China.

2.1. Heat meter method: calorimeter in each household records heat usage

A calorimeter is installed at the input and output points of a heating pipe to measure the heating consumed in each household, while a thermostatic valve is installed on each radiator to regulate heat and room temperature [11,12]. This method encourages developers to weatherize the building because poor thermal properties of building surfaces will cause higher heating consumption and costs. Heating fees will increase if the users open windows or make the room temperature set point higher, so this method can help control the user behavior of opening windows and avoid overheating the rooms.

However, there are some disadvantages with this method: (1) the primary kind of residence found in urban area in China is mainly apartment buildings, different from single-family houses in Europe and America (as Fig. 2 shows). The demand for heating in different locations of a building varies greatly due to different areas of exposure for exterior walls. Research shows that heating consumption in inner rooms is only 40% of consumption used in rooms on the top floor or at the corners of rooms even if the room temperatures of different rooms are the same. (2) Heat transfer between neighboring rooms has great impact on heat usage [13]. A series of research findings shows that heating consumption in one household may increase 20–30% if the radiators in an adjoining household are unused for a long time. Because of these factors, it is difficult for the users to accept paying for their heating fees based on heating consumption.

This method is mainly applied to private single-family houses in Europe (Finland, Germany, Austria, etc.) [14]. Although it has been used in apartment buildings in recent years, the problems with this method are as noticeable as in China for the following reasons:

1) The thermal insulation properties of the building envelope in these countries are quite good, so that differences in heating fees caused by different locations in the buildings are smaller.
2) The percentage of heating fees as a part of users' incomes is lower, so that differences in heating fees are not as noticeable to users. Total heating fees, including that for heating *and* hot water, account for only 2–5% of users' income in developed countries. However, in China, fees for heating alone can be as much as 10–30% of users' annual income. Therefore, any difference in heating fees appears very obvious.
3) Some researchers suggest that differences in heating fees due to different locations can be minimized by modifying the heating consumption value [14]. However, even in Europe, the practice of modifying the heating consumption value is controversial, and not universally applied. In fact, it is only applied in Denmark, Poland and Sweden.

In Denmark and Poland, the heating consumption value is simply multiplied by a modifying factor to minimize differences in heating fees caused by location. In Sweden, a set of complicated modifying methods has been developed. However, in Germany, this method is considered unnecessary [14] because another method of determining fees (fixed fees plus flexible fees, which will be further explained in detail) can diminish the differences. When disputes occur because differences in heating fees is too large, users who have consumed more heat can be compensated through



Fig. 2. Differences in the type of residential buildings found in China and Europe. (a) Appearance of primary residential buildings in China (multi-household apartment building). (b) Primary residential building in a developed country (single-household building).

lower prices for heating or a higher percentage of fixed fees determined by floor space. Detailed measures can be worked out through consultation.

However, in China, the structure, type and thermal insulation properties of building envelopes vary greatly. It is hard to evaluate the real impact of all the factors. A simple modifying factor will cause suspicion and dissatisfaction for all parties and is unacceptable to many users. Auditing departments for building energy consumption can resolve such problems but the cost is too high to be implemented, it is also difficult for users to adapt to such a system. Furthermore, the number of apartment buildings in China is higher compared to that in developed countries, which makes this method almost impossible to execute.

4) Managing and fee structures of apartments are different. In Europe, heating fees are determined through two stages. First, the building manager pays the heat company the total heating fees for a building and then users in the building pay the building manager. When there are disputes over differences in heating fees, the building manager can summon all the users and work out a solution by consultation, for example, a method for lower heating prices or a higher percentage of fixed fees in Germany [14]. But in China, the heat company deals with users directly, so the flexible negotiation mechanism is not applicable.

In addition, the method used to measure heating consumption on a household basis in China has lead to the following problems. (1) This method requires a household horizontal piping system, while the heating system in most existing buildings in Northern China is the single-pipe serial system. Substantial reform with piping works is needed. (2) The aperture of the current flow meters and thermostatic valves is small and the flow resistance is high, so the meters are easily blocked and damaged after being in use for a long time, affecting normal heating supply. In addition, effective external network control is necessary and a reliable control system of supply water temperature should be ensured that the thermostatic valve will perform well in controlling temperatures. However, these are difficult to change for district heating systems in China [15–18]. (3) According to the metrological laws of China, the thermal meters that are used to determine heating fees should be calibrated periodically, which causes a lot of difficulties in large-scale application. (4) The investment is too large. The investment needed for this method is about 1500–2000 RMB per household, but the cost for changing pipes is not included.

2.2. A method to distribute heating fees according to heat-allocation meters on radiators

A heat-allocation meter is installed on each radiator. The proportion of heating provided by each radiator to total heat used can be worked out by reading the heat-allocation meters so that the heating fees can be determined.

A thermostatic valve is also needed on each radiator to regulate room temperature. There are two kinds of commonly used heat-allocation meters. One is the evaporative heat-allocation meter [19]. There is a kind of special liquid (tetralin) in this meter, which is attached to the radiator surface. The relationship between the amount of evaporation and the surface temperature of the radiator is calibrated in advance and the proportion of heating provided by the radiator can be worked out according to the amount of evaporation.

The other method is by using an electronic heat-allocation meter [20], which is developed from evaporative meters. In theory, the surface temperature of the radiator and the room temperature are measured at the same time and heat needed is calculated based on the difference between the two temperatures and the heating fee then is determined.

The advantage of these two methods is that it is more convenient to apply to current heating systems without too many changes. The original vertical system does not need to be modified to a horizontal system with circles for each household. It is easier to install the evaporative meters and the cost is comparatively low. However, because the recorded heating is also the actual heating consumption, the problems previously mentioned, in that there is a big difference between different locations and issues of heat transfer between households, still exist. Therefore, Chinese users may also find it difficult to accept this method.

Furthermore, for evaporative meters: (1) when users open windows and the room temperature drops, heating provided by the radiator will increase while the value measured by the heat-allocation meter will drop because the surface temperature of the radiator drops. This contradicts the intention to reduce users opening windows. (2) Room temperature is also regulated by thermostatic valves installed on radiators, so that problems such as valves being easily blocked and ineffective temperature control are unavoidable. (3) The measuring accuracy is greatly affected by the installation quality. It can also only be applied to several kinds of radiators while there are many kinds in China. (4) The average temperature of different radiators must be maintained in a certain range, otherwise measuring inaccuracies would increase [21]. (5) Calibration of the meters and heating fee allocation also need to be managed by professional companies, so costs for investment and management is very high.

Electronic heat-allocation meters can effectively control users' behavior of opening windows because the room temperature is also measured. The accuracy is higher than evaporative meters, but the price is also higher. In addition, this kind of meter can only be applied to certain types of radiators; the application range is the same with evaporative meters and accuracy subject to the quality of installation.

2.3. A method to determine heating fees according to heated areas

The total heating consumption of a building is measured and all the users share heating fees according to their floor space. Thermostatic valves are installed on the radiators in each household and adjusted by users themselves. As described in further detail below, Finland is a good example for the application of this method [14].

However, the problems with this method include making changes with the pipe networks because thermostatic valves are needed, thermostatic valves are easily blocked and damaged, users lack incentives to save heating consumption by properly readjusting the room temperature set point, energy conservation is limited and users may continue to open windows.

There are reasons for why this method can be used in Finland: (1) the thermal insulation properties of building envelopes in Finland is excellent, ranking amongst the best in the world. The energy conservation potential to encourage people to lower the temperature set point is limited. (2) A mechanical ventilation system is used and controlled centrally in Finnish residences, so the problem of opening windows does not exist. (3) The room temperature can be controlled by two methods: thermostatic valves and sub-heating stations in each building which automatically regulates indoor temperatures according to outdoor temperatures so that room temperatures are comparatively uniform. The three aspects make energy conservation from household metering less economically viable compared to the investment on the meters.

2.4. A method to determine heating fees according to hot water meters in each household (volumetric meter)

Hot water meters are installed on both the supply and return heating pipes, which measure the accumulated hot water consumption as a percentage to determine heating fees. This method replaces the calorimeters with hot water meters at a lower cost, but is only applied in the Republic of Korea. The most important reason behind their use is the prevalence of radiant floor heating systems with small differences in household temperature between supply and return water. But using the radiator system primarily found in China, the difference is too big to be acceptable to users, as demonstration projects have shown.

2.5. A method for determining heating fees according to calorimeters in each household

A primary calorimeter is installed at the entrance of the heating pipes for each building, another calorimeter installed at the entrance of each household and a thermostatic valve installed on each radiator to regulate room temperature. The difference between this method and the household calorimeter method is that the total heating fees are paid according to the chief calorimeter while the meters in each household decide the proportion of heating fees paid by each household. The basic nature of the two methods is the same. This method can also encourage users to refrain from opening the windows and does not have the need to calibrate all the meters in each household. However, the problems with household meters still exist: heating consumption differences in different locations, heat transfer between households, blockage and damage with meters, etc. Furthermore, the investment on the chief meter needs to be added. This method is rarely used in either developed countries or China.

2.6. Determining heating fees according to room temperature

Heating fees are determined according to the average room temperature in each household. The applicable area, investment and management cost of this method are the same as those of evaporative heat-allocation meters. The major difference is that the surface temperature of radiators is replaced by the use of room temperature to guide the determination of heating fees. This method can offset the difference of heating fees caused by different locations and heat transfer amongst households. However, when users open windows, the room temperature will drop greatly while heat provided by radiators increases sharply. Users may then open windows more often to lower heating fees if they are being charged according to room temperature. This method will therefore not incentivize users to avoid opening windows and conserve energy use. This method is not allowed in Germany.

All the previous methods are summarized in Table 1 in terms of the following aspects: whether or not it can incentivize weatherizing the building, discourage users from opening windows, avoid high temperature set points and still be acceptable to users. Due to living patterns, system features and the management quality, the previous methods will either be acceptable to users or incentivize energy conservation.

3. Summary and comments

The goal of reforming the heating fee system is to promote energy conservation in buildings. However, current heat-metering methods and policies all mainly take "fairness" into account, regarding it as an effective way to reduce energy consumption by charging fairly. Some even pursue "fairness" at the expense of higher energy consumption.

For example, the method of allocating heat costs according to room temperature overemphasizes fairness. Although the difference caused by heat transfer between households and different locations can be offset, the fact that it may lead to the behavior of opening windows is overlooked. Some people even suggest adding partition walls between households or adding insulation layers onto the walls. Such suggestions are not particularly effective, as they require further investment and less usable space.

As a matter of fact, there is no absolute fairness. Too much emphasis on fairness is to focus on smaller details rather than looking at the larger picture and runs counter to the original intention. Heat metering based on individual households promotes energy conservation in buildings and reforming the fee determination system is one way to realize this goal. One major rationale behind reform is to allow users to actively participate in controlling room temperature and give users the choice to lower the set point when overheated rather than opening windows. Therefore, the standards for assessing various metering methods are primarily whether it is conducive to energy conservation and whether it is acceptable to users. It is unreasonable to say that a method is better just because it is fairer. It also does not make sense to compare which one is fairer when all could be acceptable.

The core requirements of heat-metering technologies are: (1) effective and reliable control and (2) comparatively reasonable heat-allocation method that can be acceptable to users. These two points are not equally important. The first point is the more important one and the second one is subject to the previous one. Reasonable allocation does not mean in pursuit of fairness but promoting adjustment.

Table 1
Comparison of different heat-metering methods.

		Incentivize weatherization of buildings	Users discouraged from opening windows	Too high a set point is avoided	Acceptable to users
1	Household calorimeter	✓	✓	✓	Not acceptable, as users on the top floor or in corners consume more heating
2	Evaporative heat-allocation meter	✓	×	✓	Same as the household calorimeter method in nature, not acceptable
3	Electronic heat-allocation meter	✓	✓	✓	Same as the household calorimeter method in nature, not acceptable
4	Allocation according to floor space	✓	×	×	Acceptable to most users
5	Household hot water meter	✓	✓	✓	High rate of error if applied to radiator heating system; not acceptable
6	Allocation according to household calorimeter	✓	✓	✓	Same as the household calorimeter method in nature, not acceptable
7	Allocation according to room temperature	✓	×	✓	May actually increase the behavior of opening windows; bad control method; may cause disputes; not acceptable

Based on this understanding, a new heat-metering method has emerged and has been widely used.

4. A new heat-metering method: allocation according to the on–off ratio

An on/off valve is installed for each household to regulate the room temperature in the household horizontal heating system. The hot water circulation is controlled using the on–off method to maintain the room temperature and the cumulative on-time is measured. The total heating costs are then divided up amongst households based on the on-time and floor space of each household [22,23].

There is no need to install thermostatic valves on the radiators because there are already regulating devices in this method. The advantages are primarily that (1) users behavior of opening windows and high room temperature set point can be avoided as such actions will make the cumulative on-time increase with correspondingly higher heat costs. (2) The problem of households on the top floor and corners of the building consuming more heating and heat transfer between households can be resolved. Although the amount of heat needed by households at corners or on top floor is higher, heating fees will not rise because it is determined according to the cumulative on-time and more radiators are installed. This method limits the lowest room temperature set point to be as low as 12 °C. Therefore, even when users are not present for a long time, freezing inside the room can be avoided and the influence of heat transfer between households can be diminished. (3) Practice shows that room temperature control accuracy is comparatively high (room temperature maintained in the range of set point ±0.5 °C) due to advanced intelligent control strategies. (4) There are only two states for the valves: on and off, so they are hard to block. There is also no special requirement regarding the quality of water. (5) The cost of each set of the control system can be as low as less than 700 RMB while other heat-metering methods need large investments to deal with current piping systems, thermostatic valves and heat-allocation meters. (6) This method is also more easily operated as all the data will be transmitted to a collection center through wireless devices and there is no need to go to each household and read the data.

In order to test if this method can promote users' behavior of saving energy and be accepted, 246 users (accounting for 85% of total pilot users) were surveyed by questionnaires in a pilot project. The results are as follows.

4.1. Survey on users' behavior of opening windows

Fig. 3 shows the survey results on user behavior of opening windows when heating costs are determined by consumed heating. About 92% users choose not to open windows or reduce the open window time. Fees based on heating can effectively prevent the user behavior of opening windows.

4.2. Survey on possible actions to counter overheating

Fig. 4 shows what users will do when the rooms are over heated. Result shows that 88% of users choose to lower the set point while 12% choose to open windows. Therefore decreasing the set point will become the major measure to counter overheating rather than opening windows.

4.3. Survey on the degree of satisfaction to this technology

Fig. 5 shows the degree of satisfaction of users to this technology. Result shows that 65% of users are very satisfied or satisfied, 30% of users have no opinion, and only 5% are dissatisfied.

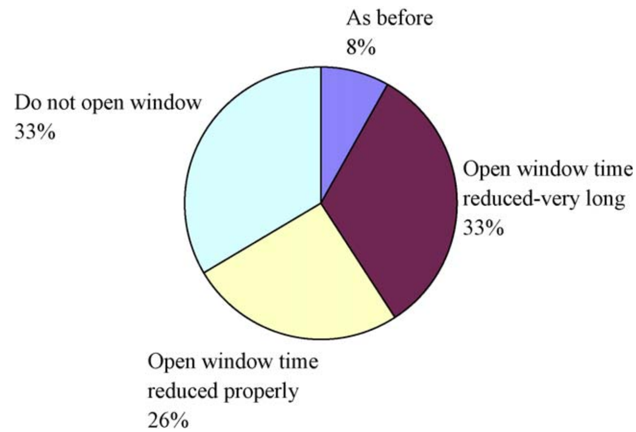


Fig. 3. Distribution of user behavior of opening windows.

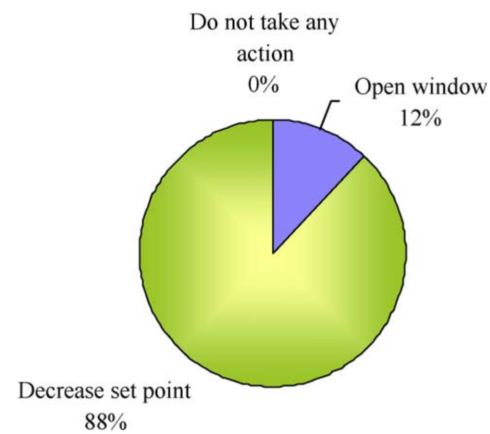


Fig. 4. Distribution of possible actions of users if the room is overheated.

4.4. The effect to encourage energy saving through economic ways

In this demonstration project, heating fees are not charged entirely according to consumed heating. So users do not have much incentive to save energy and most of them make the set point higher than what is actually desired. Data shows that 75% of users make the set point higher than 23 °C. Therefore, certain rewards according to the heat saved have been sent to the users whose room temperature set point is lower than 23 °C over a long period of time, with the cumulative on-time percentage of the valve is lower than 0.8 to encourage users to actively save energy and lower the set point.

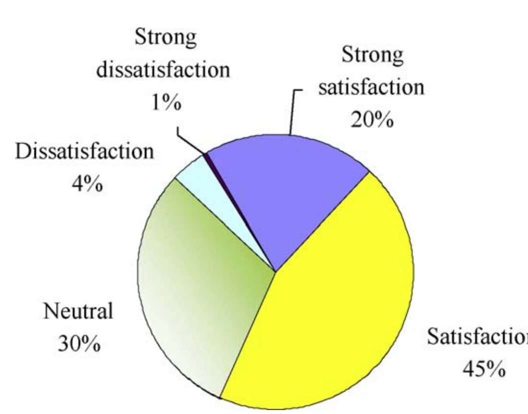


Fig. 5. Investigation results of the user satisfaction.

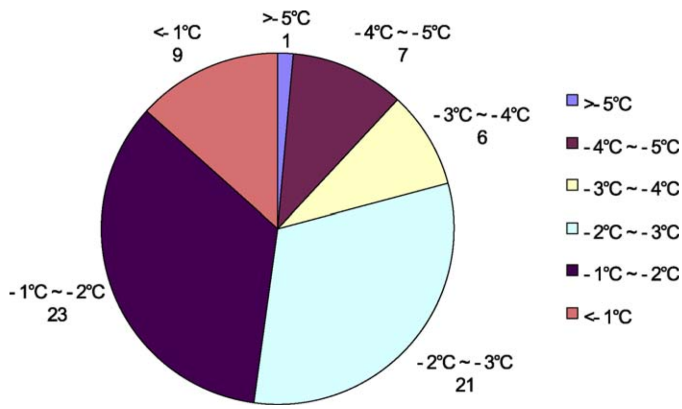


Fig. 6. Distribution of lowering set points amongst users.

On the next day of the rewards, 67 users who used to have a high set point lowered the set point themselves, with 35 users who lowered the set point more than 2 °C, with the highest drop at 6 °C. The distribution of the dropping range is as Fig. 6. It can be seen that charging based on consumed heating gives users a greater incentive to save energy when they can see immediate interests.

It can be inferred from the survey results and reward results that this technology is acceptable to users, can discourage users from opening windows, increasing set points, and promote energy conservation. Amongst the household heat-metering methods, it seems to be the best and most practical one.

4.5. About fee policies

There are three commonly used methods to determine heating fees in Europe [14,24]. In the first one, the heating fee is the heating consumed by users multiplied by price per unit (method A). In the second method, the total heating consumed by a building is measured and then the total heating fees worked out. The total heating fees are divided into two parts. One is the fixed cost (capacity cost) determined according to floor space or radiator capacity for each household. The other part is flexible (energy consumption cost) and determined according to the heating consumed by each household. The fixed part of each household changes along with the total heating fees of the building (method B). This method is more common in Germany.

In the third method, the heating fee is also divided into two parts. The first part is fixed cost determined according to floor space or radiator capacity. Different from the second way is a fixed portion does not change with the total heating fees of the building. The other part is also flexible and determined according to heating consumed by each household (method C) [25]. This method is more common in ROK and Sweden.

There are many disputes over which one of the three methods is best [14]. People in favor of method A think that the benefits to users by saving energy is largest and can motivate users to reduce energy consumption more than the other methods. People who oppose this method believe that in the countries where heating costs are very high, revenue for heat providers will drop sharply as users are keen to reduce energy consumption. This method is not acceptable to these companies because they may risk bankruptcy. Moreover, the supply of energy requires complicated infrastructure and the costs on investment and maintenance do not decrease with the amount of heat consumed by users. Therefore, there should be a fixed fee that does not change with the amount of consumed heat by users. So method C is proposed based on the previous two reasons.

One noteworthy issue is that the process of urbanization is rapidly developing in China [26]. The major problem with central heating systems is the shortage of energy supply due to high demand for heat, which differs from the situation in Eastern Europe where there is more supply than demand. Reduced energy through user conservation efforts can be supplied to other users and the heat-companies will not go bankrupt or lose profits. Furthermore, it is vital for China to further incentivize users to reduce energy consumption.

In addition, capacity fees for heating facilities was already charged onto users when constructed according to floor space, like electricity and gas. So it is unreasonable and unnecessary to charge this fee again. As for facility maintenance, one should notice that the same situation exists with electricity and gas supplies but these two utilities do not charge an extra fixed fee for maintenance. Some opponents to method A believe that users who are on the top floor, in corners of the building or those whose neighbors do not have heat consume more heat and that method B can help to reduce such differences to make it more acceptable for users. From this point of view, it is reasonable and understandable.

The allocation method according to cumulative on-time can diminish the influence of locations on heating fees but cannot fully resolve the problem of heat transfer between households. By learning from method B, we can divide the total heating fees of a building into two parts. One part determined according to floor space (to diminish the influence of heat transfer between households) and the other part determined according to the cumulative valve on-time. Such a method can be both acceptable to users and incentivize users towards energy conservation. This is the recommended method in this paper.

5. Conclusion

(1) In China, the purpose of reforming household heat metering is to promote energy conservation. The key issue is to improve controls on the system and discourage users from opening windows or setting the room temperature set point too high, as well as encourage developers to weatherize the buildings. Requirements of the heat-metering methods are: (1) incentivize developers to weatherize the buildings; (2) discourage users from opening windows; (3) avoid an overly high room temperature set point and make users turn off radiators or lower the set point when no users are present over a long period; (4) it is acceptable to users.

(2) The major living structure in China is the apartment building. If heat is measured on a household basis, the users on the top floor or in corners of the building will consume two to three times more energy than users in other locations in the building. When an adjoining apartment is not heated, heating consumption may go up 20–30%. At present, commonly used methods in Europe cannot resolve such problems and so will be unacceptable to users.

(3) For the household horizontal heating system, an on/off valve is installed on the branch for each household and then regulated according to room temperature. The accumulated on-time of each household is measured and recorded. The total heating fee of a building is determined according to the cumulative on-time as well as floor space of each household. Not only can this new method discourage users from opening windows or making the set point too high, but also resolve problems caused by location and heat transfer between households. It shows great superiority in promoting energy conservation through user actions. Survey results show that it was widely acceptable. It seems like the most practical way to carry out reforming heat metering on a household basis.

(4) Given the specific national conditions of China and for the purpose of promoting energy conservation through user actions, this paper suggests that the total heating fees for a

building be divided into two parts. One portion is a fixed fee determined according to floor space and the other portion is a flexible fee determined according to the cumulative on-time in each household.

References

[1] Tsinghua University Building Energy Research Center. 2009 annual report on China building energy efficiency. Beijing: China Architecture & Building Press; 2009 [in Chinese].

[2] Ministry of Construction of the People's Republic of China. 'Ninth five year plan' (1996–2000) and a 2010 plan of building energy saving; 1996.

[3] Ministry of Construction of the People's Republic of China. Energy conservation regulations of residential buildings; 2000.

[4] Ministry of Construction of the People's Republic of China. Guidance on a pilot project for urban heating system reform; 2003.

[5] Ministry of Construction of the People's Republic of China. Guidance for further promotion of urban heating system reform; 2005.

[6] Csoknyai I. Methods of heat cost allocation. Periodica Polytechnica Mechanical Engineering 2000;44(2):227–36.

[7] BabusHaq RF, Overgaard G, Probert SD. Heat-meter developments for CHP-DH networks. Applied Energy 1996;53(1–2):193–207.

[8] Goettling, Dieter R. Heating cost allocation in multifamily housing. ASHRAE Transactions 1984;90(1A):124–38.

[9] Yao Y, Liu S, Lian Z. Key technologies on heating/cooling cost allocation in multifamily housing. Energy and Buildings 2008;40(5):689–96.

[10] Anderson MA. Energy cost allocation in multifamily buildings using comfort-based allocation devices. ASHRAE Transactions 1993;99(1):899–906.

[11] Danfoss A/S. Radiator thermostats RTC/RTD. Danfoss data sheets; 2001:12.

[12] British Standards Institution. BS EN 215:2004 Thermostatic radiator valves—requirements and test methods.

[13] Pakanen J, Karjalainen S. Estimating static heat flows in buildings for energy allocation systems. Energy and Buildings 2006;38(9):1044–52.

[14] JP Building Engineers (Espoo/Finland), Center for Energy Efficiency in Buildings (Beijing/China). Heat metering and billing: technical options, policies and regulations. In: Chinese demonstration projects and international experiences; 2002.

[15] Weker P, Mineur JM. A performance index for thermostatic radiator valves. Applied Energy 1980;37(6):203–15.

[16] Bobker M, Kinsley EL. Balancing apartment building heating with thermostatic radiator valves. Heating Piping and Air Conditioning 1995;67(9):47–56.

[17] Liao Z, Swainson M, Dexter AL. On the control of heating systems in the UK. Building and Environment 2005;40(3):343–51.

[18] Rusjan B. Conventional control of hydronic heating of apartment buildings according to the modernization of measure and control elements. Elektrotehniski Vestnik 1998;65(2–3):108–15.

[19] Heat Cost Allocators for the Detection of the Consumption of Radiator. Appliances Based on the Principle of Evaporation, Appliances with Subsidiary Electrical Energy Supply, EN835..

[20] Heat Cost Allocators for the Detection of the Consumption of Radiator. Appliances with Electrical Energy Supply, EN834..

[21] Goettling DR. Heat emission rates of hydronic terminal elements and their relationship to heating cost allocation devices. ASHRAE Transactions 1993;99(1):888–98.

[22] Liu L, Fu L, Wang C, et al. A novel on–off TRV adjustment model and simulation of its thermal dynamic performance. Building Simulation 2009;2(2):29–40.

[23] Liu LB, Fu L, Jiang Y. A novel "wireless on–off control" technique for household heat adjusting and metering in district heating system. In: ASME 3rd international conference on energy sustainability (ES2009); 2009.

[24] Meyer A. The international experience of the heat price determination and charging policy. In: The international symposium on heat price determination and charging policy in China; 2003.

[25] Kalkum B. Guidance on the heat price determination in China. In: The international symposium on heat price determination and charging policy in China; 2003.

[26] Li B, Yao R. Urbanisation and its impact on building energy consumption and efficiency in China. Renewable Energy 2009;34(9):1994–8.